Few-Body Systems Suppl. 0, 1–?? (2013)

Few-Body Systems

Nucleon structure functions in a constituent quark scenario *

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Abstract. Using a simple picture of the constituent quark as a composite system of point-like partons, we construct the polarized parton distributions by a convolution between constituent quark momentum distributions and constituent quark structure functions. We achieve good agreement with experiments in the unpolarized as well as in the polarized case, though a good description of the recent polarized neutron data requires the introduction of one more parameter. When our results are compared with similar calculations using non-composite constituent quarks, the accord with the experiments of the present scheme is impressive. We conclude that DIS data are consistent with a low energy scenario dominated by composite constituents of the nucleon.

At low energies, the so called naive quark model accounts for a large number of experimental observations. At large energies, QCD sets the framework for an understanding of the Deep Inelastic Scattering (DIS) phenomena beyond the Parton Model. However, the perturbative approach to QCD does not provide absolute values for the observables. The description based on the Operator Product Expansion (OPE) and the QCD evolution requires the input of non-perturbative matrix elements. We have developed an approach which uses model calculations for the latter ingredients [1]. Moreover, in order to relate the constituent quark with the current partons of the theory, a procedure, hereafter called ACMP, has been applied [2, 3]. Within this approach, constituent

Supported in part by DGICYT-PB94-0080 and TMR programme of the European Commission ERB FMRX-CT96-008; based on two talks given at: 1) Workshop "N Physics and non perturbative QCD", Trento, Italy, May 18-29 1998, to be published in Few Body Systems, Suppl.; 2) Conference "Fev Body 16^{th}", Autrans, France, June 1-6, 1998, to be published in Few Body Systems, Suppl.

quarks are effective particles made up of point-like partons (current quarks (antiquarks) and gluons), interacting by a residual interaction described as in a quark model. The hadron structure functions are obtained by a convolution of the constituent quark model wave function with the constituent quark structure function. This idea has been recently used to estimate the pion structure function [4]. We summarize here our application to the unpolarized [3] and polarized [5] DIS off the nucleon. It will be found that DIS data are consistent with a low energy scenario dominated by composite constituents.

In our picture the constituent quarks are themselves complex objects whose structure functions are described by a set of functions Φ_{ab} that specify the number of point-like partons of type b, which are present in the constituents of type a with fraction x of its total momentum [2, 3]. In general a and b specify all the relevant quantum numbers of the partons, i.e., flavor and spin. Let us discuss first the unpolarized case for the proton [3].

The functions describing the nucleon parton distributions omitting spin degrees of freedom are expressed in terms of the independent $\Phi_{ab}(x)$ and of the constituent probability distributions u_0 and d_0, at the hadronic scale μ_0^2 [1], as

$$f(x,\mu_0^2) = \int_x^1 \frac{dz}{z}[u_0(z,\mu_0^2)\Phi_{uf}(\frac{x}{z},\mu_0^2) + d_0(z,\mu_0^2)\Phi_{df}(\frac{x}{z},\mu_0^2)] \tag{1}$$

where f labels the various partons, i.e., valence quarks (u_v, d_v), sea quarks (u_s, d_s, s), sea antiquarks $(\bar{u}, \bar{d}, \bar{s})$ and gluons g. The different types and functional forms of the structure functions for the constituent quarks are derived from three very natural assumptions [2]: *i)* The point-like partons are the quarks, antiquarks and gluons described by QCD; *ii)* Regge behavior for $x \to 0$ and duality ideas; *iii)* invariance under charge conjugation and isospin.

These considerations define the following structure functions [2]

$$\Phi_{qf}(x,\mu_0^2) = C_f x^{a_f}(1-x)^{A-1} \ , \tag{2}$$

where $f = q_v$, q_s, g for the valence quarks, the sea and the gluons, respectively. Regge phenomenology suggests: $a_{q_v} = -0.5$ (ρ meson exchange) and $a_{q_s} = a_g = -1$ (*pomeron* exchange). The other ingredients of the formalism, i.e., the probability distributions for each constituent quark, are defined according to the procedure of ref. [1] and shown in [3]. Our last assumption relates to the hadronic scale μ_0^2, i.e., that at which the constituent quark structure is defined. We choose $\mu_0^2 = 0.34$ GeV^2, as defined in Ref. [1], namely by fixing the momentum carried by the various partons. This choice of the hadronic scale determines all the parameters except one, which is fixed through the data [3]. To complete the process, the above input distributions are NLO-evolved in the DIS scheme to the experimental scale, where they are compared with the data.

We next generalize our previous discussion to the polarized parton distributions. As it is explained in ref. [5], using $SU(6)$ (spin-isospin) symmetry and other reasonable simplifying assumptions, it can be shown that

$$\Delta f(x,\mu_0^2) = \int_x^1 \frac{dz}{z}[u_0(z,\mu_0^2)\Delta\Phi_{uf}(\frac{x}{z},\mu_0^2) + d_0(z,\mu_0^2)\Delta\Phi_{df}(\frac{x}{z},\mu_0^2)] \ , \qquad (3)$$

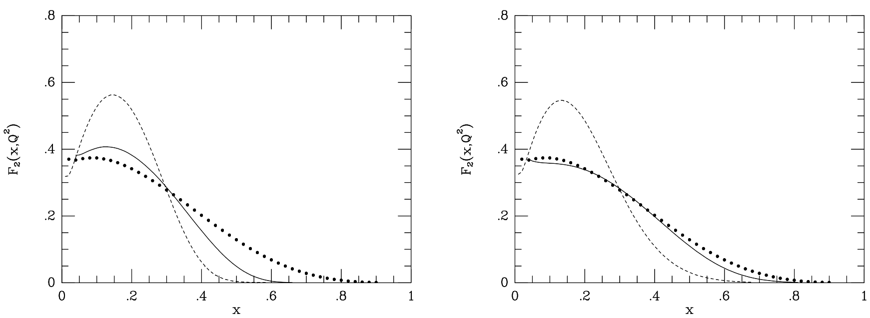

Figure 1. The proton $F_2(x,Q^2)$, obtained by NLO-evolution to $Q^2 = 10$ GeV^2 (full), compared to the data (dots) [10]. The result which would be obtained disregarding the constituent structure is also shown (dashed). Left (right) panel: constituent wave functions form ref. [8] (ref. [9]).

where f labels the various partons; it means that the $ACMP$ procedure can be extended to the polarized case just by introducing three additional structure functions for the constituent quarks: $\Delta\Phi_{qq_v}$, $\Delta\Phi_{qq_s}$ and $\Delta\Phi_{qg}$. In order to determine them we add two minimal assumptions: *iv)* factorization: $\Delta\Phi$ cannot depend upon the quark model used; *v)* positivity: the constraint $\Delta\Phi \leq \Phi$ is saturated for $x = 1$. In such a way we determine completely the $\Delta\Phi$'s. In fact, the QCD partonic picture, Regge behavior and duality imply that

$$\Delta\Phi_{qf} = \Delta C_f x^{-\Delta a_f}(1-x)^{\Delta A_f - 1} \qquad (4)$$

and $-\frac{1}{2} < \Delta a_f < 0$, for all $f = q_v, q_s, g$, as allowed by dominant exchange of the A_1 meson trajectory [7]. Moreover, the assumption that the positivity restriction is saturated for $x = 1$, in the spirit of ref. [6], implies that the $\Phi's$ and the $\Delta\Phi's$ have the same large x behavior, and that $\Delta C_f = C_f$, (the latter being introduced in (2)); it means that the partons which carry all of the momentum also carry all of the polarization. Let us stress that the change between the polarized functions and the unpolarized ones comes only from Regge behavior; as a matter of fact, it turns out that, *except for the exponent* Δa_f shown above, the $\Delta\Phi$'s, Eq. (4), are given by the unpolarized functions, Eq. (2). The other ingredients, i.e., the polarized distributions for each constituent quark, are defined according to the procedure of ref. [1] and they are shown in ref. [5]. Finally, the parton distributions at the hadronic scale are evolved to the experimental scale by performing a NLO evolution in the AB scheme [7]. Results are shown in Figs. 1 and 2. Fig. 1 refers to the unpolarized case. The structure function $F_2(x,Q^2)$, obtained evolving the parton distributions Eq. (1), calculated using Eq. (2) for the Φ_{qf}'s and two different models for u_o

and d_o, describes successfully the data. The agreement becomes impressive if compared with a similar calculation with non-composite constituents.

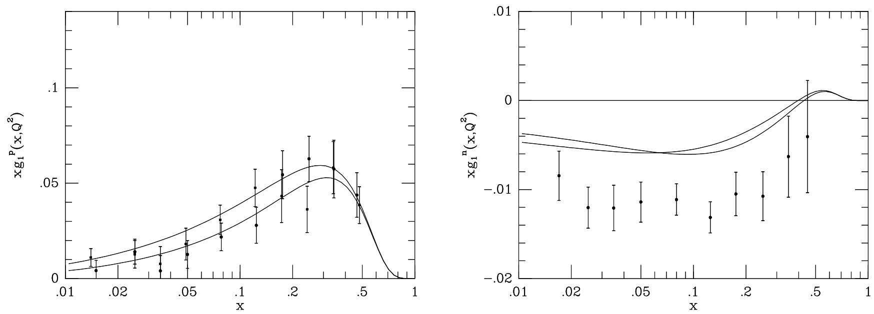

Figure 2. Left (Right): $xg_1(x,Q^2)$ for the proton (neutron) evolved at NLO to $Q^2 = 10\,(5)$ GeV^2, for the two extreme Regge behaviors mentioned in the text (full curves). The wave functions used are from ref. [9]. The data [10] are shown for comparison.

In the polarized case, it is found [5] that the constituent structure functions Eq. (4) give a good result for the proton, but they fail in reproducing the recent precise neutron data. This is to be ascribed to our naive input for the sea and to the symmetry for the u and d quarks [5]. In particular, it has been shown that, by redefining the sea $\Delta\Phi$, changing *only one* parameter so that the experimental sea polarization is recovered, also the neutron is rather well described. Fig. 2 refers to this last scenario. The procedure is also able to predict successfully several observables, such as the nucleon axial charges [5]. It should be noticed that in this framework the *spin crisis*, as initially presented, does not arise.

Summarizing, low energy models seem to be consistent with DIS data when a structure for the constituent is introduced. The crucial role played by the sea in the polarized case, as well as the implementation of Chiral Symmetry Breaking in our procedure, have to be more deeply investigated. It will be the subject of future work.

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